

Quantum Universe

The Revolution in 21st-Century Particle Physics

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QUANTUM UNIVERSE

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HIGH ENERGY PHYSICS ADHOC EF PANEL
QUANTUM UNIVERSE COMMITTEE

The Charge

- “Recent scientific discoveries at the energy frontier and in the far reaches of the universe have redefined the scientific landscape for cosmology, astrophysics and high energy physics, and revealed new and compelling mysteries.”
- “We are writing to ask the High Energy Physics Advisory Panel (HEPAP) to take the lead in producing a report which will illuminate the issues, and provide the funding and science policy agencies with a clear picture of the connected, complementary experimental approaches to the truly exciting scientific questions of this century.”
- ↪ This report is the opportunity to describe why this is the most exciting time in particle physics in over a half a century, if not much longer.

Membership of the Committee

- ★ Andreas Albrecht
UC Davis
- ★ Sam Aronson BNL
- ★ Jon Bagger JHU
- ★ Keith Baker Hampton
- ★ Neil Calder SLAC
- ★ Persis Drell SLAC
- ★ Evalyn Gates
U of Chicago
- ★ Fred Gilman
CMU
- ★ Judy Jackson FNAL
- ★ Steve Kahn SLAC
- ★ Rocky Kolb FNAL
- ★ Joe Lykken FNAL
- ★ Hitoshi Murayama
U C Berkeley
- ★ Hamish Robertson
U of Washington
- ★ Jim Siegrist
U C Berkeley
- ★ Simon Swordy
U of Chicago
- ★ John Womersley FNAL

Schedule

- ☐ Weekly telecons since mid-October
- ☐ Trip to DC: 11/18
- ☐ Face to face at SLAC: 1/20
- ☐ Draft of Rougher Text: 2/1
- ☐ Draft of Rough Edited Text: 2/15
- ☐ Complete Draft: 3/1
- ☐ Review by Committee: 3/23
- ☐ Final Draft Text to HEPAP: 4/1
- ☐ Discussion with HEPAP: 4/19
- ☐ Follow through in Washington and with the community after approval of HEPAP

What we heard from our Customers

- Talked to Customers (11/18/03)
 - Holland, Looney, Marburger, Parriott, Turner, Staffin, Dehmer, Orbach
- What we heard:
 - Lead with the science!
 - We see a large array of tools that are seemingly unconnected.
 - “Why can’t we discover the Higgs with ICECUBE?”
 - Articulate the questions that are driving the field
 - give a roadmap: how will we answer these questions, what is the toolkit?
 - Show how scientific questions map onto experimental space
 - How are the different tools connected?
- We have taken this input very seriously

Organization of Report

- Layered document
 - Increasing technical detail
 - Repetition is important
- Executive Summary
 - Stand alone document
 - Articulates the questions that define the field
 - Does not include map of tools onto questions

Organization of Report (cont.)

□ Main Document: Five sections

I. Introduction

II. The Fundamental Nature of Matter and Energy, Space and Time

- Introduces the nine questions
- Explains questions in language for non expert (appropriate for Congressional staffer)

III. Tools for a Scientific Revolution

- Repeats questions
- Articulates questions in more technical detail (appropriate for agency people; assumes significant familiarity with HEP program)
- Discusses tools to make progress

IV. Conclusions

V. Summary Tables

- Requested by Customers

The Questions

Einstein's Dream of Unified Forces

1. Are there undiscovered principles of nature: new symmetries, new physical laws?

The quantum ideas that so successfully describe familiar matter fail when applied to cosmic physics. Solving the problem requires the appearance of new forces and new particles signaling the discovery of new symmetries—undiscovered principles of nature's behavior.

2. How can we solve the mystery of dark energy?

The dark energy that permeates empty space and accelerates the expansion of the universe must have a quantum explanation. Dark energy might be related to the Higgs field, a force that fills space and gives particles mass.

3. Are there extra dimensions of space?

String theory predicts seven undiscovered dimensions of space that give rise to much of the apparent complexity of particle physics. The discovery of extra dimensions would be an epochal event in human history; it would change our understanding of the birth and evolution of the universe. String theory could affect the way the force of gravity behaves.

4. Do all the forces become one?

At the most fundamental level all forces and particles in the universe may be related, and all the forces might be manifestations of a single grand unified force, realizing Einstein's dream.

The Questions (cont.)

The Particle World

5. Why are there so many kinds of particles?

Why do three families of particles exist, and why do their masses differ so dramatically? Patterns and variations in the families of elementary particles suggest undiscovered underlying principles that tie together the quarks and leptons of the Standard Model.

6. What is dark matter? How can we make it in the laboratory?

Most of the matter in the universe is unknown dark matter, probably heavy particles produced in the big bang. While most of these particles annihilated into pure energy, some remained. These remaining particles should have a small enough mass to be produced and studied at accelerators.

7. What are neutrinos telling us?

Of all the known particles, neutrinos are the most mysterious. They played an essential role in the evolution of the universe, and their tiny nonzero mass may signal new physics at very high energies.

The Questions (cont.)

The Birth of the Universe

8. How did the universe come to be?

According to cosmic theory, the universe began with a singular explosion followed by a burst of inflationary expansion. Following inflation, the universe cooled, passing through a series of phase transitions and allowing the formation of stars, galaxies and life on earth. Understanding inflation requires breakthroughs in quantum physics and quantum gravity.

9. What happened to the antimatter?

The big bang almost certainly produced equal amounts of matter and antimatter, yet the universe seems to contain no antimatter. How did the asymmetry arise?

Primary US Physics Program of Major Facilities

	Unification				Particle World			Birth of the Universe	
Question	1	2	3	4	5	6	7	8	9
Tevatron	X				X				
LHC	X	X	X					X	
Linear Collider	X	X	X	X		X			
NuMI/MINOS							X		
ν Superbeams							X		X
BaBar	X				X				X
BTeV	X				X				X
JDEM		X				X			
RHIC								X	
Proton Decay				X					

Primary US Physics Program of Smaller Facilities

	Unification				Particle World			Birth of the Universe	
Question	1	2	3	4	5	6	7	8	9
Mini-BooNE							X		
MECO	X				X				
Reactor ν Experiments							X		
CLEO-c					X				
K0PI0									X
Neutrinoless Double Beta Decay				X			X		
SDSS						X			
LSST		X				X			
Underground Dark Matter Detectors						X			
WMAP		X				X		X	
CMB Polarization								X	
Lattice Computational Facilities					X			X	
Precision Gravity			X						

Challenges we faced

- The Questions
 - Making the questions inclusive
 - Making the questions exciting and understandable
- Balance
 - Traditional HEP vs. 'The New Cosmology'
 - Remember the audience!
- Precision vs. Accuracy vs. Clarity
 - Can't explain everything
 - Remember the audience!
 - Judy and Neil invaluable in guiding us here
- Title
 - 'Quarks to the Cosmos' a hard act to follow!
 - 'Quantum Universe' is at least memorable

Challenges we faced (cont.)

☐ Facilities

a. What is mentioned in text

- ☐ Tried to be inclusive of all major experiments with submitted proposals, in construction, or in operation, with scientific goals germane to the questions we are asking
- ☐ Included proposed experiments on DOE facilities outlook and NSF MRE list with scientific goals germane to the questions we are asking
- ☐ Included both US and International efforts

b. When to be generic and when to be specific?

- ☐ Judgment call by the committee on a case by case basis
 - ☐ e.g. 'Neutrinoless Double Beta Decay' vs. EXO and Majorana
 - ☐ e.g. ' ν superbeams' instead of CERN SPL, FNAL/BNL proton driver, JPARC Phase II, etc....
 - ☐ e.g. BTeV and LHC-b instead of 'Hadron B-factories'

Challenges we faced (cont.)

c. What is included in table?

- ☐ Focused on facilities with major US participation
- ☐ Only listed experiments whose primary scientific goals are directed at the questions we are asking.
 - ☐ Judgment call on the part of the committee to not include all experiments mentioned in text in the table
 - ☐ Wanted to avoid a laundry list
 - ☐ Remember to listen to the customers!

d. What does bold face mean and how is it used?

- ☐ When an experiment or facility gets a check in the table for a given question it appears in bold in the corresponding text in section III
 - ☐ The use of bold face is confusing
 - ☐ We have developed an alternative scheme to highlight facilities (e.g. sidebar next to the question)

EINSTEIN'S DREAM OF UNIFIED FORCES

Superstrings and grand unification are currently the most promising ideas for fulfilling Einstein's dream of an ultimate theory. To understand string theory requires experimental tests of its predictions of supersymmetric particles, and extra dimensions of space. To understand unification requires experiments sensitive to extremely rare particle decays. To contrast the discrepancy between the theory of the large and the theory of the small requires a better understanding of fundamental quantum physics.

1. ARE THERE UNDISCOVERED PRINCIPLES OF NATURE: NEW INSTRUMENTS, NEW PHYSICAL LAWS?

EXPERIMENTAL PROCEDURE

THEORY	DATA
UGC	Linear Collider
ETAP	MECC

The quest for Nature derives from the Universe's symmetry, searching for new particles and forces reveals breaking for new symmetry. One such symmetry might be supersymmetry, which predicts that for every known particle there exists a supersymmetric partner of the same mass. Experiments have not yet detected any of the supersymmetric, that, if supersymmetry exists, it must be hidden by additional physical that make supersymmetric particles heavy. Supersymmetric matter may be related to the Higgs field; supersymmetry provides a natural dark matter candidate, the gravitino. Experiments are searching for supersymmetry directly at the Tevatron and indirectly at the Relativistic Heavy Ion Collider.

The Tevatron may have enough energy to produce detectable signals of the lightest supersymmetric. The LHC should have enough energy to produce all or much of the supersymmetric particles, either directly or through the decay of other supersymmetric, to determine the pattern of supersymmetric matter and decay.

A Linear Collider would measure the properties of the supersymmetric very precisely, showing that they are indeed the supersymmetric of known particles; it could study the properties of the lightest supersymmetric least likely the gravitino with great precision. The correlation between the dark matter content of the Universe at a Linear Collider, correlated with precision measurements of other supersymmetric, would produce a prediction for the cosmic relic density of gravitinos to determine whether the predictions are consistent with the dark matter hypothesis.

Theoretical models for the physical mechanism that break supersymmetry are already constrained by data from Belle and BaBar. Future precision studies at Belle and BaBar, as well as from the future hadron Relativistic Heavy Ion Collider and LHC, will allow physicists to distinguish the decay structure of supersymmetry through subtle changes

in decays of B mesons. The MECC experiments will provide unprecedented sensitivity to the direct production of neutral (the electron) at Tevatron, and some models of supersymmetric gravitino production predict for that process that MECC will observe.

2. HOW CAN WE SOLVE THE MYSTERY OF DARK ENERGY?

EXPERIMENTAL PROCEDURE

WEP	LEIT
ECR	LHC
Future Collider	

The dramatic discovery of dark energy showed that empty space is filled with a mysterious energy that dominates all the universe expansion. While Einstein originally proposed a cosmological constant that would explain the dark energy, it is the amount of dark energy that is difficult to understand. The natural source of such a dark energy field, quantum fluctuations of the vacuum, gives a density of dark energy 10^{-120} times larger than observed levels.

An interesting program is at place to study the properties of dark energy. Measurements of the fluctuations and distribution of the cosmic microwave background from WMAP, correlated with data from cosmological structure formation, especially its pattern in clusters, suggests that dark energy is consistent with a cosmological constant. Future measurements of supernovae, gravitational lensing, and direct observation from LEIT, the Large Synoptic

DARK ENERGY PROBE will be in tandem to investigate with new scientific concepts.

Survey Telescope, and JDEM, the Joint Dark Energy Mission, will reveal definitively whether dark energy inherent like Einstein's cosmological constant or like some new substance that changes with time at the cosmic scale.

To determine what dark energy is and why it exists requires understanding the cosmic evolution of dark energy in a better fundamental understanding of microscopic quantum physics. At the microscopic level, physicists have long known that "empty" space is not empty; it is filled by a field that gives quanta and forms these matter in the Standard Model, that field is called the Higgs mechanism at the LHC will find the corresponding Higgs particle.

Facilities Included

- ☐ Tevatron
- ☐ LHC
- ☐ Linear Collider
- ☐ NuMI/MINOS
- ☐ ν Superbeams
- ☐ BaBar
- ☐ BTeV
- ☐ JDEM
- ☐ RHIC
- ☐ Proton Decay

- ☐ SNO, SuperK, KamLand, K2K, JPARC, Cern to GS
- ☐ BELLE, LHC-b
- ☐ RIA, Underground Laboratory
- ☐ GLAST, VERITAS, ICE CUBE, AMS, PLANK, SPT, ACT, LIGO

- ☐ Mini-BooNE
- ☐ MECO
- ☐ Reactor ν Experiments
- ☐ CLEO-c
- ☐ KOPIO
- ☐ Neutrinoless Double Beta Decay
- ☐ SDSS
- ☐ LSST
- ☐ Underground Dark Matter Detectors
- ☐ WMAP
- ☐ CMB Polarization
- ☐ Lattice Computational Facilities
- ☐ Precision Gravity



TEXT but *not* TABLE



TEXT and TABLE

Challenges we faced (cont.)

- ☐ How are check marks in the table assigned?
 - Highlight facilities with greatest impact
 - Orthogonality
 - ALL CHOICES A JUDGEMENT CALL ON THE PART OF THE COMMITTEE
 - ☐ Much discussion
 - ☐ Unanimous agreement with final decisions
 - Examples of difficult choices
 - ☐ Q6: (Dark Matter) LC gets a check, LHC does not
 - ☐ Neutrino experiments checked for Q7 (What are ν telling us) but not Q5 (Why so many particles)
 - ☐ Q9: (Antimatter) did not include Tevatron

Summary

- ❑ Committee worked extremely well together and has produced what we hope will be a useful document
- ❑ Will listen and incorporate comments from HEPAP
- ❑ Final printed version with pictures and sidebars is in final design stages with production anticipated by May 14
- ❑ Next steps are follow through with customers and community

Connecting Quarks with the Cosmos

1. What is Dark Matter? ★
2. What is the Nature of Dark Energy? ★
3. How Did the Universe Begin? ☆
4. Did Einstein Have the Last Word on Gravity?
5. What are the Masses of the Neutrinos and How Have They Shaped the Evolution of the Universe ☆
6. How Do Cosmic Accelerators Work and What are They Accelerating?
7. Are Protons Unstable?
8. What are the New States of Matter at Exceedingly High Density and Temperature?
9. Are There Additional Space-Time Dimensions? ★
10. How Were the Elements from Iron to Uranium Made?
11. Is a New Theory of Matter and Light Needed at the Highest Energies? ☆